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EFFECT OF FIN ARRANGEMENTS ON AERODYNAMIC CHARACTERISTICS OF A THICK 74° DELTA MANNED LIFTING ENTRY VEHICLE AT LOW-SUBSONIC SPEEDS

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EFFECT OF FIN ARRANGEMENTS ON AERODYNAMIC CHARACTERISTICS OF A THICK 74° DELTA MANNED LIFTING ENTRY VEHICLE AT LOW-SUBSONIC SPEEDS*

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SUMMARY

A force-test investigation has been made to determine the low-subsonic static aerodynamic characteristics of a model of the horizontal-lander 10 (HL-10) manned lifting entry vehicle with several fin arrangements. The results of the study indicated that the model was directionally unstable with tip fins alone which were designed primarily from hypersonic considerations. Directional stability was achieved, however, by the addition of a center fin in conjunction with the tip fins. The configuration with this three-fin arrangement was found to be longitudinally stable. The investigation also indicated that a fighter type of canopy had almost no effect on the longitudinal characteristics of the model with the center fin but could have a considerable effect on the lateral characteristics, depending on its fore and aft location on the body.

INTRODUCTION

The National Aeronautics and Space Administration is conducting a number of investigations to provide aerodynamic data from hypersonic to low-subsonic speeds for various winged and lifting-body configurations designed for entry into the atmosphere of the earth. One of the current lifting-body configurations under simultaneous study throughout the speed range is the manned entry vehicle designated HL-10 (horizontal-lander 10). The results published to date on this configuration consist of data obtained at hypersonic speeds (refs. 1 and 2), at supersonic speeds (ref. 3), at transonic speeds (ref. 4), and at low-subsonic speeds (ref. 5).

The present investigation, which is a continuation of the low-speed study reported in reference 5, was made with the HL-10 model which had a 74° delta planform and a thick negatively cambered airfoil section. It was shown in reference 5 that the original vertical tip fins of this configuration were ineffective for providing the model with directional stability at low-subsonic speeds.

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The present investigation was made to provide information at low-subsonic speeds on the static longitudinal and lateral characteristics of the HL-10 model with an alternate tip-fin configuration which was found to be satisfactory at hypersonic speeds. (See ref. 2.) Also presented are the effects of a center fin with the alternate tip fins and the effects of a canopy, such as used on a fighter aircraft, on the aerodynamic characteristics of the model. The investigation included static force tests over an angle-of-attack range from 0° to 45°.

SYMBOLS

The lateral data are referred to the body system of axes and the longitudinal data are referred to the wind axes. (See fig. 1.) The origin of the axes was located to correspond to a longitudinal center-of-gravity position of 53 percent of the body length. The coefficients are based on a planform area of 6.6 square feet, a body length of 4.3 feet, and a span of 2.8 feet.

b span, ft

C_L lift coefficient, L/qS

C_l rolling-moment coefficient, M_X/qSb

ΔC_l incremental rolling-moment coefficient

$C_{l_\beta} = \frac{\Delta C_l}{\Delta\beta}$ per degree

C_m pitching-moment coefficient, M_Y/qSl

$C_{m,o}$ pitching-moment coefficient at zero lift

C_n yawing-moment coefficient, M_Z/qSb

ΔC_n incremental yawing-moment coefficient

$C_{n_\beta} = \frac{\Delta C_n}{\Delta\beta}$ per degree

C_Y side-force coefficient, F_Y/qS

ΔC_Y incremental side-force coefficient

$C_{Y_\beta} = \frac{\Delta C_Y}{\Delta\beta}$ per degree

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F_Y side force, lb

L lift, lb

l body length, 4.3 ft

M_X rolling moment, ft-lb

M_Y pitching moment, ft-lb

M_Z yawing moment, ft-lb

q dynamic pressure, $\rho V^2/2$, lb/sq ft

S planform area, sq ft

V free-stream velocity, ft/sec

X,Y,Z body reference axes

x distance from nose of model to canopy

α angle of attack, deg

β angle of sideslip, deg

δ_e elevator deflection, positive with trailing edge down, deg

ρ air density, slugs/cu ft

APPARATUS AND MODEL

The model was tested in a low-speed tunnel with a 12-foot octagonal test section at the Langley Research Center. A sting support system and internally mounted three-component strain-gage balances were used in the investigation.

A three-view drawing of the basic body is presented in figure 2(a). The body has a 74° delta planform with a thick negatively cambered airfoil section. The body ordinates of the model (to a smaller scale) may be found in reference 1. The detail in figure 2(a) shows the action of the independently hinged upper and lower surfaces of the elevator of the model. The deflection angle of the elevator is defined as the angle between the surface moving into the airstream (upper surface for upward deflection and lower surface for downward deflection) and the extension of the corresponding body contour line.

Sketches of the vertical fins and canopy used in the investigation are presented in figure 2(b) and have been identified as described below:

Fin A: Original tip fins, toed in 16°

Fin D-2: Alternate tip fins, toed in 16° and rolled out 30° from the vertical (the "-2" indicates that there are slight differences in geometry of the fins used in this investigation and those of refs. 2 and 3)

Fin E: Center fin used in reference 6

Fin K: Center fin made by removing the upper 40 percent of the span of fin E

Canopy A: Canopy, such as used on a fighter aircraft

Basic body: Body without fins

TESTS

Static force tests were made to determine the longitudinal and lateral characteristics of the model throughout an angle-of-attack range from 0° to 45°. The lateral stability characteristics were determined from tests at angles of sideslip of ±5°. Included in the investigation were tests to determine effects of various vertical-fin arrangements and the effects of a fighter type of canopy on the aerodynamic characteristics of the model. The tests were made at a dynamic pressure of 4.1 pounds per square foot and a velocity of 58.8 feet per second, which corresponds to a Reynolds number based on the model body length of 1.6×10^6.

RESULTS AND DISCUSSION

It was shown in reference 1 that the HL-10 configuration with the original tip fins (fin A in this report) had satisfactory longitudinal and lateral aerodynamic characteristics at hypersonic speeds. Reference 5, however, pointed out that at low-subsonic speeds, fins A (when toed in at their design angle of 16°) created a local flow separation and thus were ineffective in providing the model with directional stability. Reducing the tip-fin toe-in angle improved the directional stability characteristics, but the configuration was still unstable. It was found that by removing the tip fins and adding a center vertical fin (fin E) the HL-10 model could be made directionally stable. A center fin, however, was believed to be ineffective at hypersonic speeds above an angle of attack of about 20° because the fin would become shielded from the flow. The investigation reported in reference 2 indicates various methods of obtaining directional stability at hypersonic speeds. Tip fins D-2 (comparable to fin D of ref. 2), which appeared promising at high speeds, were investigated to determine their effect on the low-speed aerodynamic characteristics of the HL-10 configuration.

Lateral Characteristics

The lateral-stability data are presented in the form of the variation of the stability derivatives C_{Y_β}, C_{n_β}, and C_{l_β} with angle of attack. The values of the derivatives were obtained by taking the difference between the values of the coefficients measured at sideslip angles of $\pm5^\circ$. Because the derivatives were only measured at sideslip angles of $\pm5^\circ$ and may be nonlinear throughout a large sideslip range, the data should be used only to provide approximate comparisons of the various configurations and to indicate trends.

Effect of vertical fins.- The effect of the vertical-fin configurations on the lateral characteristics of the HL-10 model studied to date are presented in figure 3. The lateral characteristics of the basic body and the basic body with fin A or E are taken from reference 5 for comparison with the lateral characteristics of the basic body with fin D-2 and with fin D-2 along with center fin E or K. It may be seen that the model with fin D-2 alone was directionally unstable at low angles of attack. Above an angle of attack of about 25°, however, the configuration became increasingly stable throughout the remaining range. The addition of fin E to the model with fin D-2 produced a configuration that was directionally stable at low angles of attack and had very high values of positive stability at the higher angles of attack. In order to reduce the directional stability level, fin E was modified to form fin K (fig. 2(b)). The combination of fins D-2 and K provided the configuration with small values of positive stability at low angles of attack and values approximately equal to those of D-2 alone at the higher angles of attack. These data, then, indicate that a center fin of at least the size of fin K is needed along with fin D-2 to provide directional stability at low-subsonic speeds. Further investigation of the model with fin D-2 together with fin K was discontinued, however, when deficiencies were discovered at low-supersonic speeds.

Effect of canopy.- It is conceivable that a spacecraft of the HL-10 type may require a canopy for pilot vision for maneuvering and landing the vehicle. The model with center fin E was fitted and tested with a fighter type of canopy to determine the effects of a canopy on the lateral characteristics. These data are presented in figure 4 and show that the canopy was destabilizing to such an extent that the configuration was directionally unstable above an angle of attack of about 9°. The destabilizing effect of the canopy was felt to be greater than that produced by the addition of side area ahead of the center of gravity and was probably a combination of side area and resultant change in flow across the center fin. A fairing in the form of a thin flat plate extending from the canopy to the center fin (fig. 2(b)) was added to the model in an attempt to improve the flow over the center fin. This fairing allowed the configuration to retain the shape of the C_{n_β} curve that was established with the canopy off, but the curve was displaced negatively so that the model was unstable at low angles of attack.

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Effect of canopy position.- In order to study the effects of the canopy on the lateral characteristics of the model more closely, a series of tests was made in which the position of the canopy was varied rearward from the nose of the model. These data are presented in figure 5 and show a large decrease in directional stability at angles of attack near 30° that became less as the canopy was moved aft. The data also show that as the canopy was moved rearward the shape of the C_{n_β} curve for the canopy on approaches the shape of the curve for the canopy off. It is also seen that the canopy was moved to about the 20-percent body station before the configuration became stable across the complete angle-of-attack range. At this rearward position, the effectiveness of the canopy would be seriously compromised from the standpoint of pilot visibility because the shape of the upper surface of the body and the high angles of attack required by this type of vehicle at landing would greatly limit the pilot's view of the horizon and landing area. A more forward canopy location with acceptable directional stability might be obtained, however, by the addition of tip fins and/or the addition of a fairing, as presented in figure 4.

Longitudinal Characteristics

Effect of vertical fins.- The effect of the various fin configurations on the longitudinal characteristics of the HL-10 model is presented in figure 6. Again, as in the case of the lateral characteristics, the data for the basic body and body with fin A or E are taken from reference 5. The data show that the addition of fin D-2 had, in general, the same effects as did the addition of the original tip fins (fin A); that is, an increase in longitudinal stability at low angles of attack, a negative shift in the pitching-moment curve, an increase in lift-curve slope, and a shift in the lift curve so that the angle of attack for zero lift was reduced.

Effect of elevator deflection.- The effect of elevator deflection on the longitudinal characteristics of the model with fins D-2 and E is presented in figure 7. It is seen that deflecting the elevator did not greatly affect stability of the model. The elevator effectiveness remained nearly constant over the deflection range tested (0° to -20°) and produced stable trim points at angles of attack from 0° to about 31°.

Effect of canopy.- The effect of the fighter type of canopy on the longitudinal characteristics of the HL-10 model with center fin E is given in figure 8. These data show that the canopy had virtually no effect on the longitudinal characteristics of this configuration.

SUMMARY OF RESULTS

Force tests have been made to determine the low-subsonic static aerodynamic characteristics of a model of the horizontal-lander 10 (HL-10) manned lifting entry vehicle with several fin arrangements. The results of the study indicated that the configuration with tip fins (fin D-2), which had 16° of

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toe-in and 30° of roll-out, was ineffective in providing the model with directional stability. Directional stability was achieved, however, by the addition of a center fin in conjunction with fin D-2. The configuration with this three-fin arrangement was longitudinally stable.

The investigation also indicated that a fighter type of canopy had almost no effect on the longitudinal characteristics of the model with the center fin but could have a considerable effect on the lateral characteristics, depending on its fore and aft location on the body.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 29, 1963.

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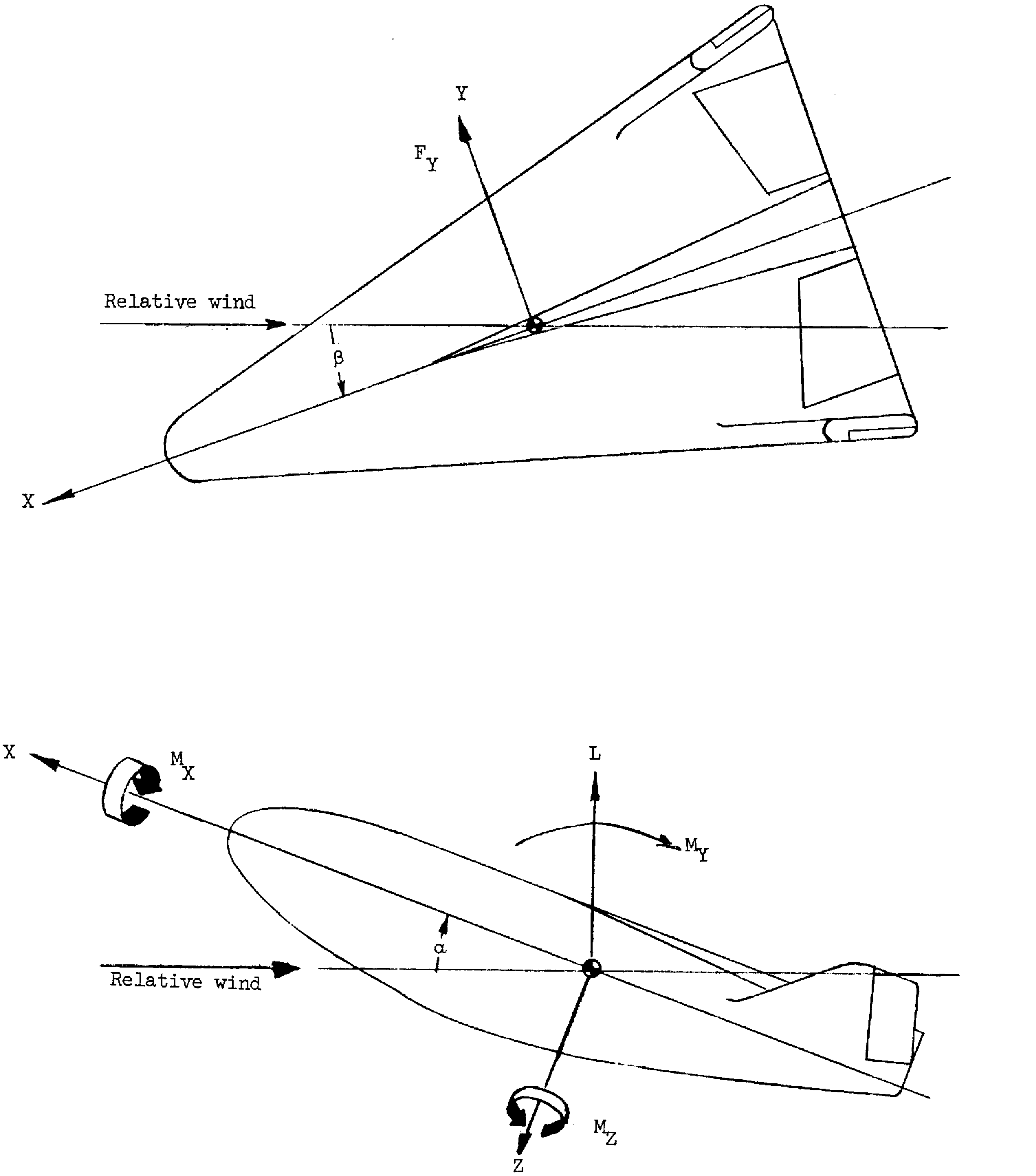
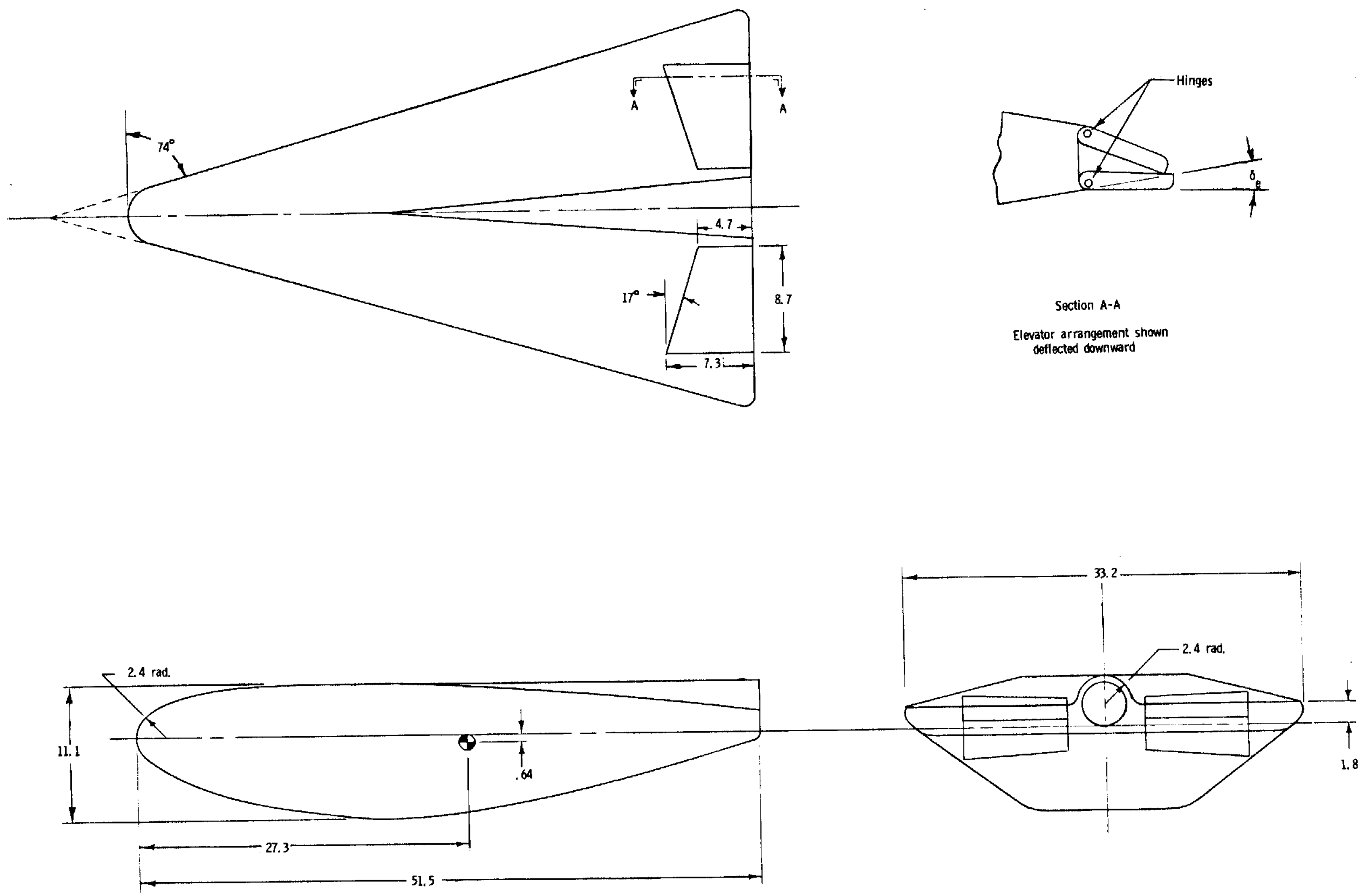
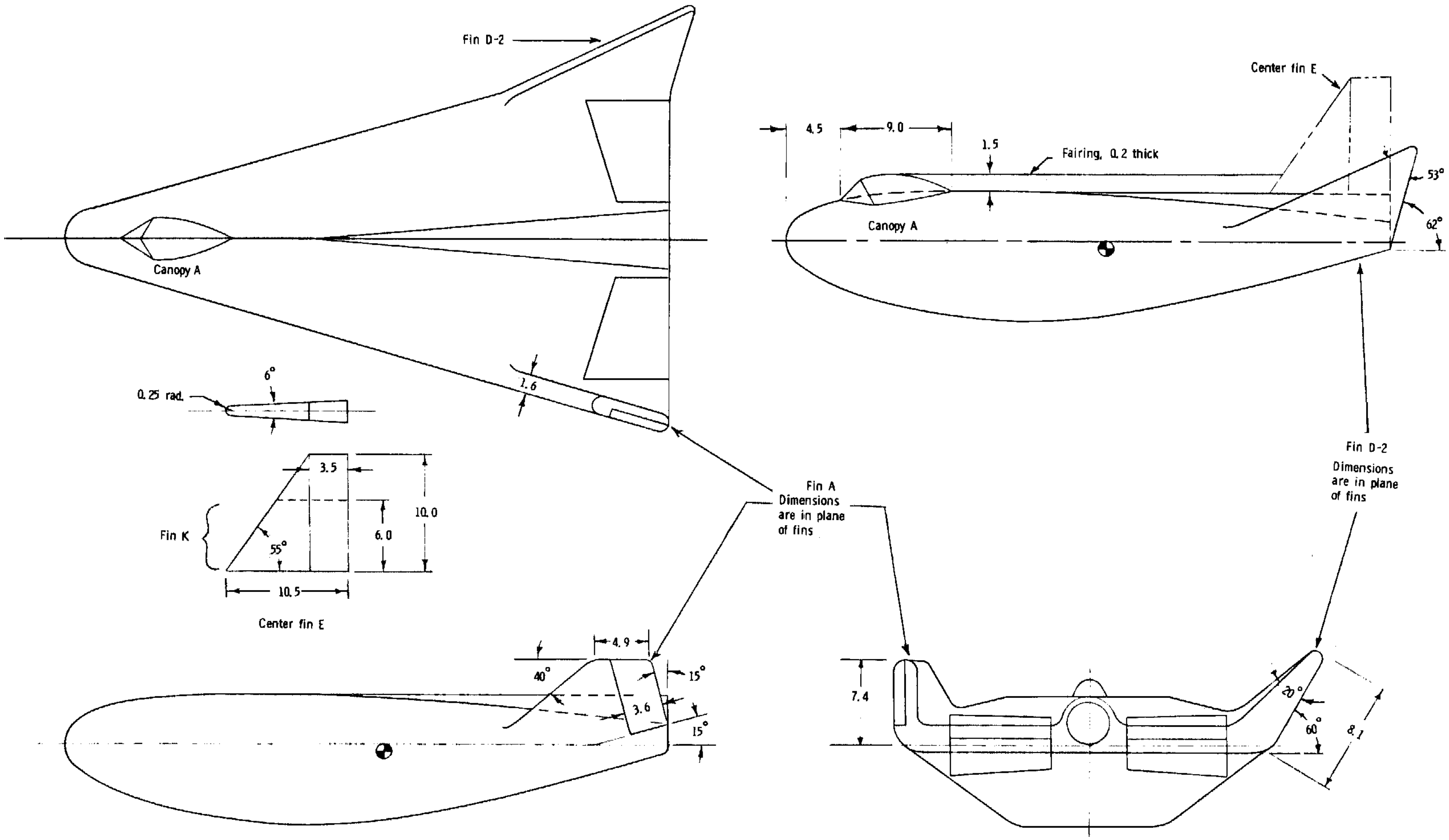


Figure 1.- Sketch of axis system used in investigation. Arrows indicate positive direction of forces, moments, and angles.



(a) Basic model.

Figure 2.- Sketch of model used in investigation. All linear dimensions are in inches unless otherwise noted.



(b) Details of vertical fins and canopy. (Note: Fin D-2 is toed in 16°.)

Figure 2.- Concluded.

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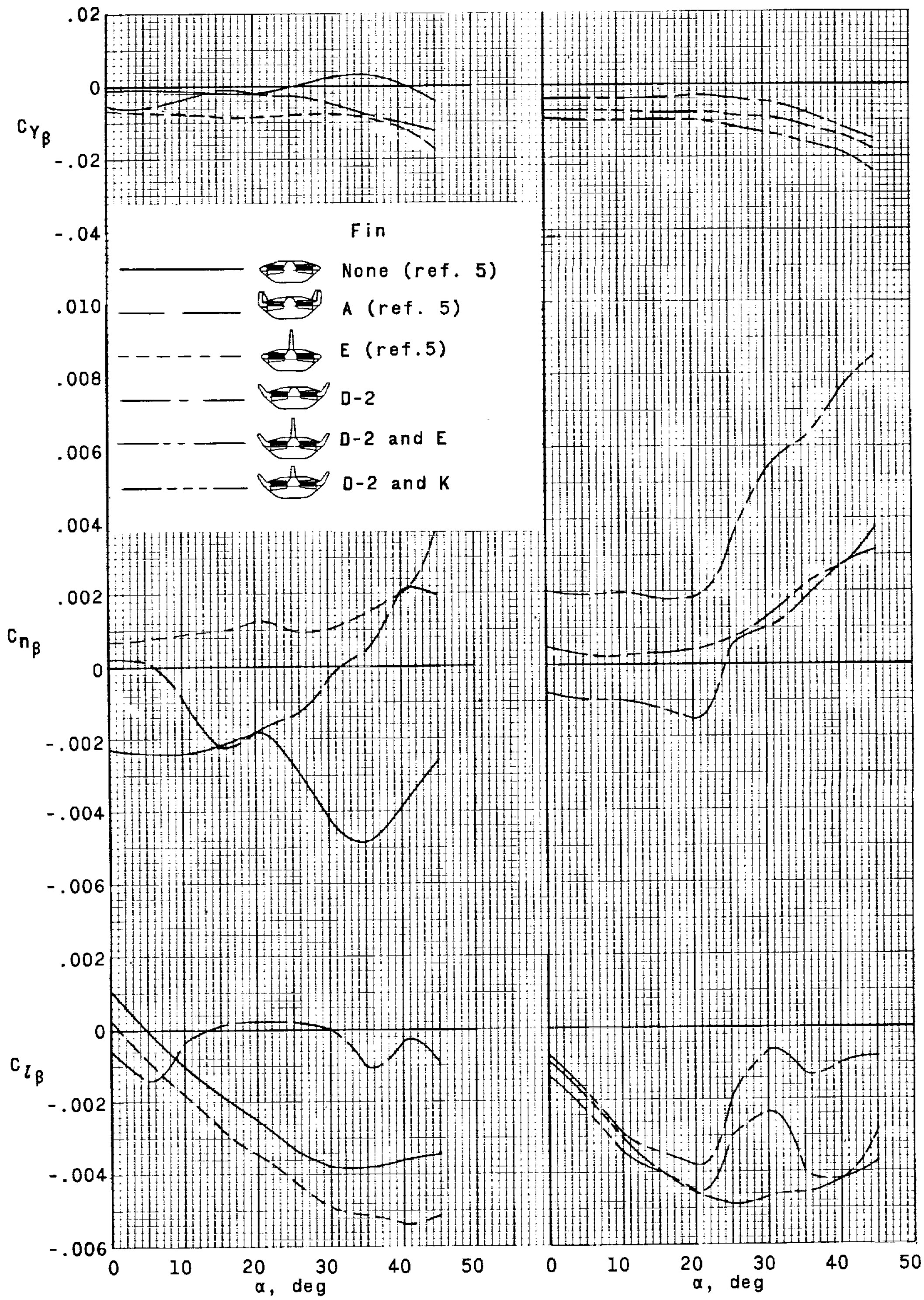

Figure 3.- Effect of fin configuration on lateral characteristics of HL-10.

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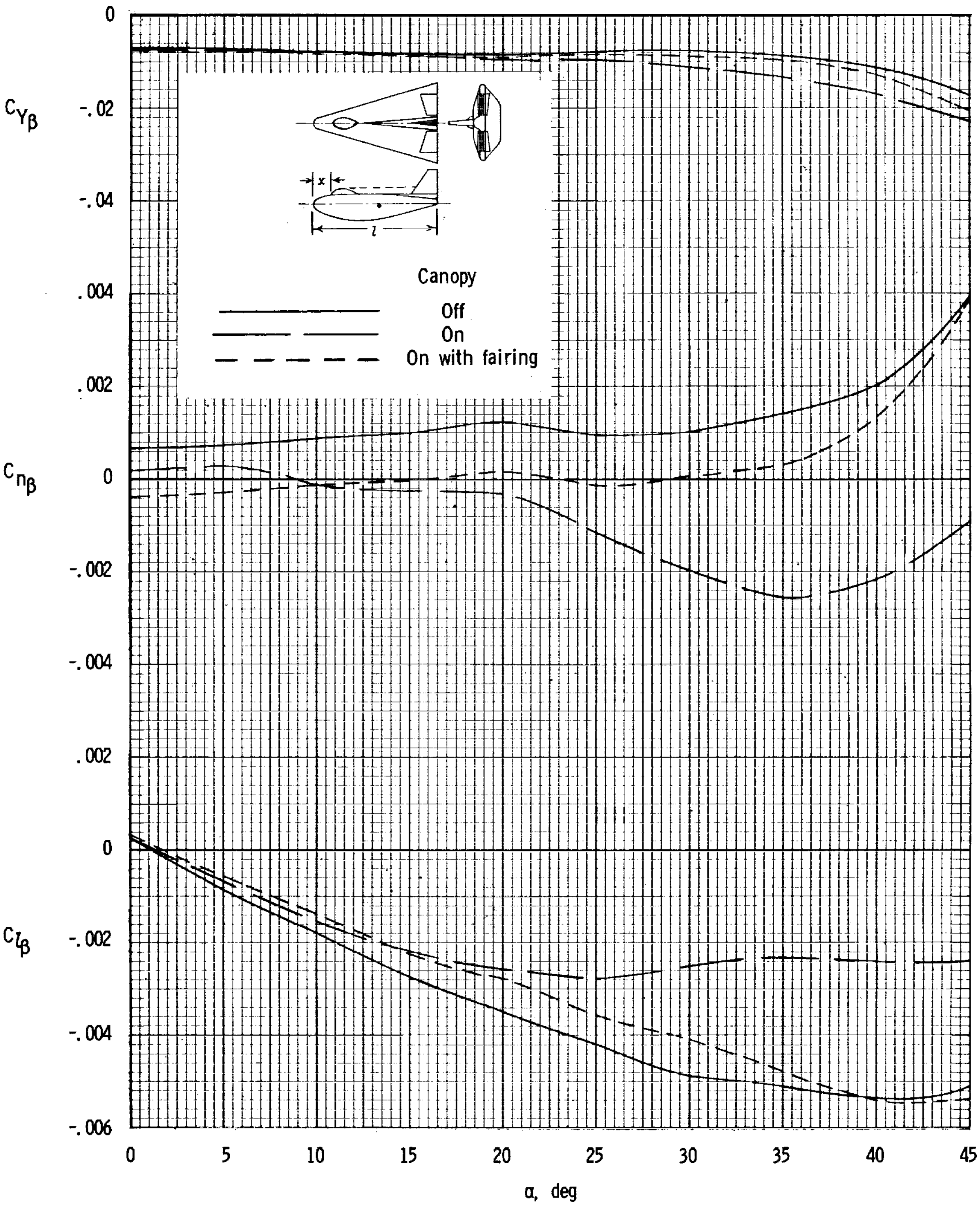

Figure 4.- Effect of canopy on lateral characteristics of HL-10 with center fin E. $x/l = 0.085$.

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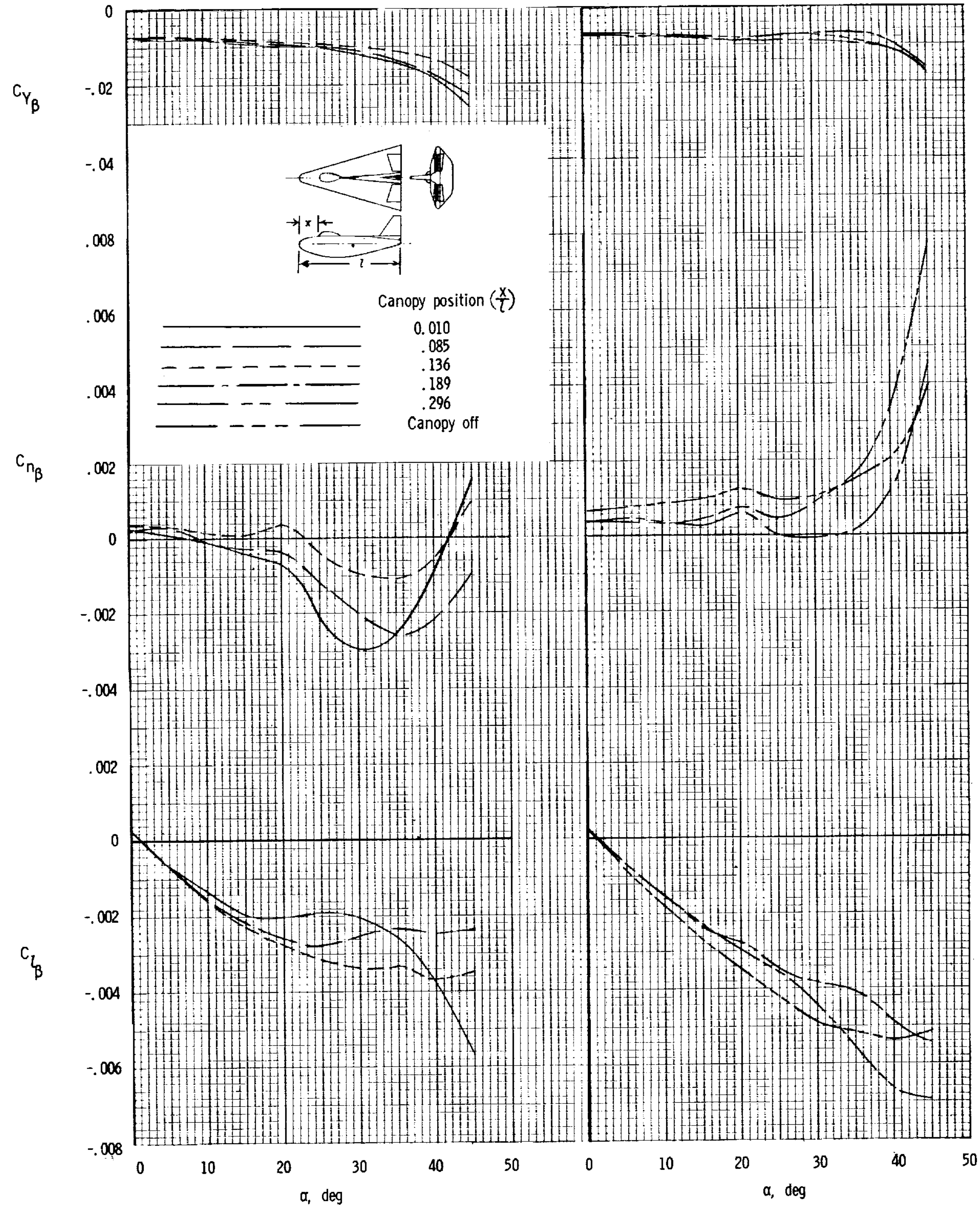

Figure 5.- Effect of canopy position on lateral characteristics of HL-10 with center fin E.

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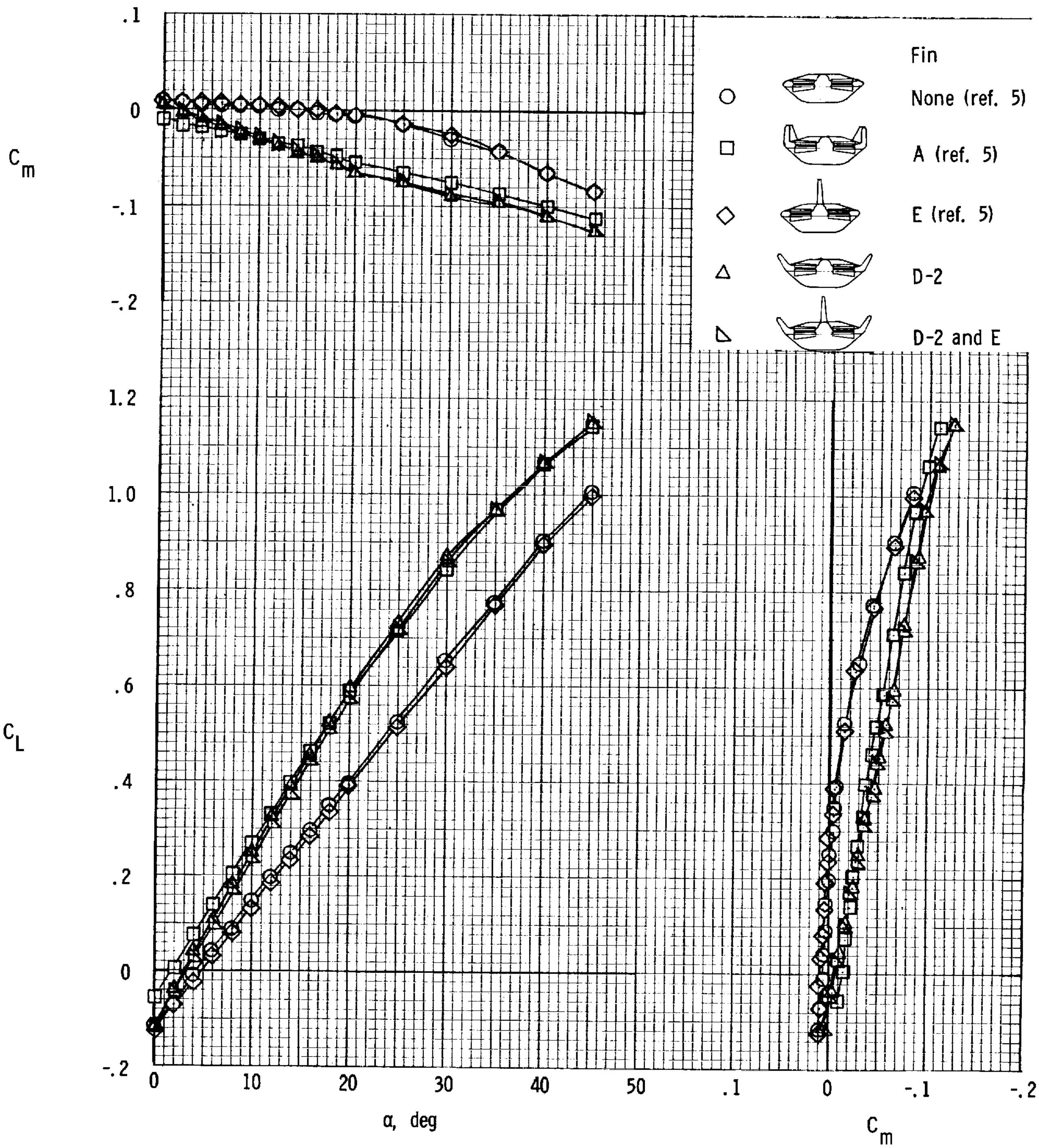

Figure 6.- Effect of fin configuration on longitudinal characteristics of HL-10. $\beta = 0^{\circ}$.

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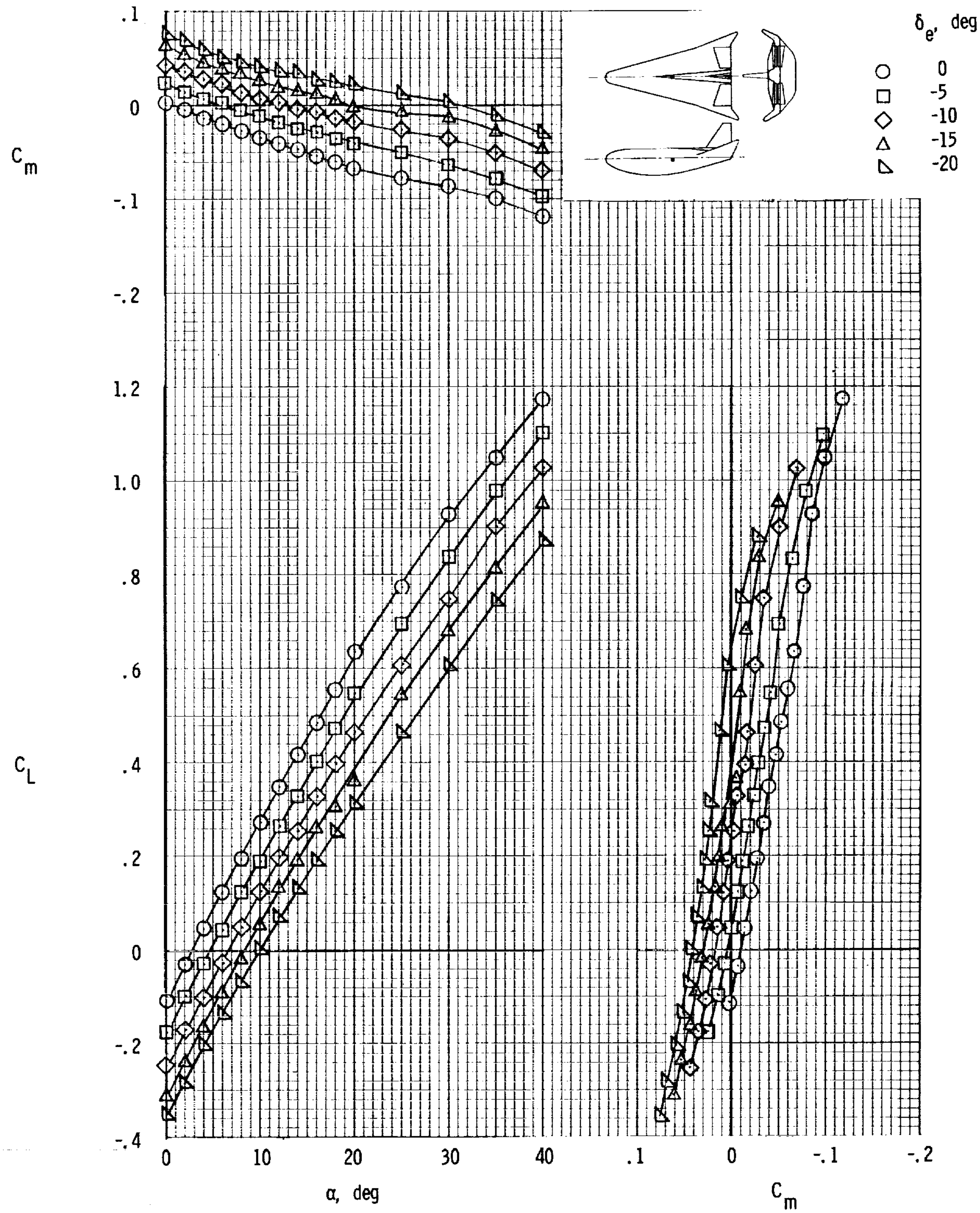

Figure 7.- Effect of elevator deflection on longitudinal characteristics of HL-10 with fins D-2 and E. $\beta = 0^{\circ}$.

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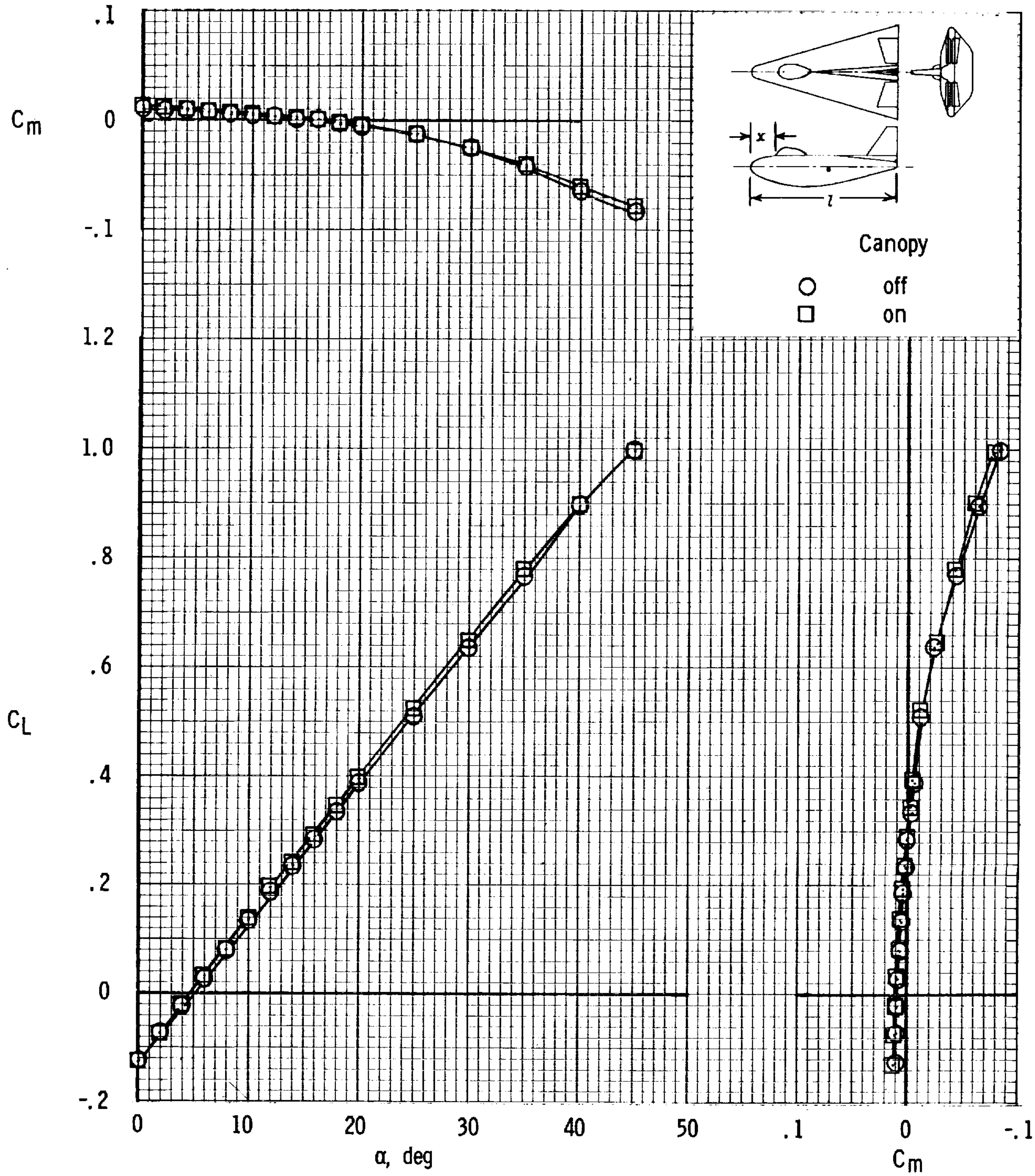

Figure 8.- Effect of canopy on longitudinal characteristics of HL-10 with center fin E. $x/l = 0.085$; $\beta = 0^{\circ}$.

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